Bt Cotton in KwaZulu Natal: Technological Triumph but Institutional Failure

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Abstract

In the1998/1999 season, Bt cotton was commercially released to Zulu smallholders in Makhatini Flats, KwaZulu Natal and by 2001/2 over 90% of the approximately 3500 farmers in the area had adopted Bt varieties. This in itself suggests that Bt cotton was successful and all the studies that have been conducted confirm that Bt cotton offers advantages. The benefits are increased yield and decreased use of insecticides, which improved income and lowered costs more than enough to offset the higher seed costs, so profits rose. With several years of data, it is clear that the relative magnitudes of the benefits depend on the weather and that single surveys give very variable answers. There can be social costs in terms of job losses, if cutbacks in spraying and fetching water are not counter-balanced by output increases requiring more weeding and harvest labour. There are also social benefits, as less pesticide residues reduce damage to the soil, water and wildlife and improve health. Studies in China, Argentina and Mexico, which are the other developing countries where farmers are using Bt, show the same variability in benefits. For African smallholders, we would expect the yield effect to be important due to the initial situation, in which the relatively advanced farmers in these other countries were using sufficient pesticides to deal with the bollworm effectively, whereas pesticide use in Makhatini Flats was well below the required level. Thus, technologically Bt looks like an excellent technology for other African countries, but Makhatini also serves as a warning that institutional failure is the norm rather than the exception in Africa. In the last two seasons, cotton production has been drastically reduced, due to lack of credit.

1. Background[1]

South Africa is the only African country in which GM cotton and maize have been commercially released. Bt cotton contains the genes controlling the production of a natural insecticide, Bacillus thuringiensis (Bt), which acts specifically on Lepidoptera, including bollworm in cotton and stem borers in maize, and is harmless to all other insects.

In 1998, the smallholders in Makhatini Flats, a rain fed cotton area in North East KwaZulu Natal, began adopting Bt cotton. A Monsanto report [2] shows that in 1998/99, there were 75 adopters, growing less than 200 hectares of Bt cotton. In 1999/2000, this rose to 411 adopters with a little under 700 hectares, and in 2000/1, to 1184 adopters with about 1900 ha. Thus, in only three years, 40% of the producers, representing almost two thirds of the area planted, have adopted the

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[1] Almost all of this background information, including that in the original report to DFID is reported in [1].

new technology and preliminary results showed that by 2001/2 over 90% had adopted Bt varieties [3].

Monsanto owns the Bt gene, used by Delta Pineland in developing the varieties used, which up to 1999/0 was mainly NuCOTN 37-B and in 2000/1 NuOpal was added , commonly called Bollgard. Several modern non-GM varieties were also available from the sole supplier of seeds and chemicals in Makhatini Flats, which was Vunisa Cotton (Zulu for "to harvest"). This is a private company, which also provided support services for the farmers through their extension officers, including credit for land preparation, chemicals and seed. Credit was crucial, as most farmers cannot afford to grow cotton without it and the forthcoming crop was the only collateral. Vunisa was able to lend on this basis because it was the sole buyer, sending the cotton to their gin in Pongola.

The main source of information is a survey of 100 farmers, conducted jointly by University of Pretoria and University of Reading, covering the 1998/99 and 1999/2000 seasons. Information was collected on household background, farming practices and problems, the reasons for adopting Bt cotton and input costs and returns. Rather than relying on farmer recall, most of the crucial information used in evaluating the technology came from farm records supplied by Vunisa.

The smallholders are all Zulus and there were no large commercial producers. Cropping land is unfenced, so livestock damage crops due to the communal grazing system. Due to out migration of younger men, 42% of the household heads were female and 76% were over forty years old. Mixed cropping is the norm, with an assortment of maize, beans and vegetables, grow for subsistence and cotton, which is usually the only cash crop. As is common in South Africa, most households (75%) also kept livestock and almost 30% had a source of income other than the farm, such as the police service, truck driving and mining. Over 60% of the farmers "owned" less than five hectares of land, with the largest concentration, of 37%, in the 2.5-5 hectare group. Cotton areas varied from one hectare to a single farm of twenty-five hectares.

Evaluating the technology is complicated by two factors. In the first year farmers with less than 5 hectares had an average yield of 510kgs/ha and only 15% adopted the Bt variety. Those with over 5 hectares produced only 378 kgs/ha and 25% were adopters. Thus, any simple comparison will be biased by this positive correlation of farm size with adoption and its negative correlation with yield.

2. Assessing the Bt Technology: Farm Management Accounting[2]

The farm accounting efficiency measures, based on Vunisa's data, are reported in Table 1, beginning with the first season. The first column covers the 18 Bt adopters and the second, the 82 non-adopters. Then, the non-adopters are split between the 40 farmers who did not adopt in either year and the 42 who adopted Bt in the second season. This division allows the innate differences between farms to be separated from the effects of the Bt technology. The first row shows that in the first season the adopters produced an average of 475 kgs per hectare, as compared with 457 for the non-adopters. Neither the 40 non-adopters or the 42 second year adopters are using Bt seed in this first year and they averaged 423 kgs per hectare and 493 kgs per hectare, respectively.

Thus, there is no clear yield advantage to the Bt variety, as the second year adopters have the highest yields, which are 4% higher than the adopters as well as being 16.5% higher than the group who never adopt, who are using the same technology. The lack of advantage may be

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[2] This section is fully covered in [4], which superseded earlier work such as [1], [5] and [6].

explained by the correlations noted in the last section and by the seeding rate (seed used per unit of land) of 0.43 bags per ha, which is 22% lower than for the full set of non-adopters, probably because of the cost of the seed (197 Rand per hectare compared with 119 Rand for all the non-adopters). However, pesticide costs are lower for the adopters (93 Rand per hectare, compared with 132 Rand). The extra cost of seed can be set against the savings on pesticides and the increase in output, since the gross margin is defined as the value of output minus the costs of intermediate inputs.

Table 1: Comparison of non-adopters and adopters: costs and returns (per hectare)

	First season – 1998/99				**Second season – 1999/2000**			
	Bt cotton		**Non-Bt cotton**			**Bt cotton**		**Non-Bt**
Averages per category	1st year adopters	All non-adopters	Adopted neither year	2nd year adopters	All adopters	1st year adopters	2nd year adopters	Adopted neither year
Number of farmers	18	82	40	42	60	18	42	40
Yield (kg/ha)	475	457	423	493	425	433	421	304
Bags (25kg) of seed / ha	0.43	0.55	0.55	0.53	0.46	0.46	0.46	0.57
Yield (kg) / kg of seed	50	37	32	42	44	40	46	23
Seed cost / ha (Rand)	197	119	124	115	214	211	214	127
Chemical cost / ha (Rand)	93	132	145	120	83	83	83	129
Gross Margin / ha (Rand)	781	791	687	890	675	673	676	428

However, the gross margins show that the non-adopters were actually 10 Rand better off, because although the Bt adopters got almost 100 Rand per hectare more than those who never adopt, they are over 100 Rand worse off than the second year adopters. Thus, neither yields nor gross margins explain why none of the adopters discontinued the Bt variety and a further 42 adopted in the next year. The obvious flaw in these commonly used measures of productivity and profitability is that the cost saving in labour used for spraying is not taken into account and 20% of the farmers rated this as the main reason for adoption. Net margins do include labour and land costs, but cannot be calculated since although the survey data includes the quantities of labour and land, neither land nor family labour has a price. However, the quantities alone show that the farmers who had a significant increase in yield did not use less labour, as the increase in harvest labour compensated for the reduction in labour for spraying.

The right hand side of Table 1 reports the results for the second season, when the lower yields are attributable to late heavy rains, which were 50% above average, compared with the lower than average rain at the beginning of the previous year. Whereas the first season was good for the cotton crop, the second was not. The average yield of the non-adopters fell to 304 kgs per hectare, a decline of 28%. The first important outcome is that all adopters had an average yield of 425 kgs per ha, which is 40% higher than the non-adopters, leaving little doubt that the Bt variety yields better in a wet year, when bollworm are a greater problem, because the rain washes the pesticide residue off the plants. But, since by these measures the second year adopters appear to be the best farmers, what proportion of this 40% increase is actually attributable to the Bt variety?

The second year adopters, who had 16.5% greater yields than the non-adopters, when using the same seed, now have a 38.5% yield advantage after adopting the Bt variety. Thus, the yield benefit due to the Bt variety appears to be 22%, or close to 70 kgs per hectare. The percentage gain is in line with Monsanto's field trials (for the first season, which was a good year) that show a 27% yield gain for the Bt variety [2, Table 1].

The second result is that the decline for those who used Bt in both years was only from 475 to 433 kgs per hectare (a 9% fall), whereas for those who changed to Bt in the second year, the fall was from 493 to 421 kgs per hectare (a 15% fall). Despite switching to the Bt technology, the second year adopters now have lower yields than the first year adopters, which suggests that there is learning by doing by the second season. Average seed costs per hectare were 68% higher for adopters in this second season, as the Bt seed costs nearly twice as much. However, chemical costs fell by 36%, from 129 Rand for non-adopters to 83 Rand for adopters. Monsanto's field trials show a reduction from 220 Rand per hectare for the non-Bt variety to 23 for Bt cotton, a reduction of almost 90%. Therefore, much of the trial plot gains in chemical reduction have not occurred at the farm level in this bad season.

Even so, the second year results are far clearer and the outcome entirely unambiguous. The yield gain of 40% and the lower chemical cost easily offset the extra seed cost, so that the average gross margin for the adopters is 675 Rand compared with 428 Rand for the non-adopters, which is 58% higher. The share of this that is attributable to the Bt variety can be calculated as it was for yields. The advantage of the second year adopters was 30% when the two groups used the same seed and is now 58%, so 28% can be attributed to the Bt variety, which is worth 190 Rand per hectare. Again, this result can be compared with Monsanto's trial results, which showed a gain of 944 Rand per hectare, due to higher trial plot yields and a greater reduction in chemical use.

This is as far as simple farm management measures using the original two years of data can be taken. There are more Vunisa records, but we considered them too messy and incomplete to use, which is a pity as they also covered Tonga in Mpumalanga, which is the other smallholder area. These Vunisa records are used in [7], [8] and [9], but the results reported are seriously at odds with the earlier work of the same authors, [5] that was based on the survey. In 2003/4 there has been a small but careful sample survey conducted by University of Pretoria and CIRAD and the preliminary results show that in this drought year there is no significant yield advantage to the Bt variety. Thus, the variations due to the weather mean that any study based on a sample for a single year can be entirely misleading. If it is true that there is zero gain in some years and substantial advantages in others, we can say with confidence that the expectation is positive and that Bt seems to reduce the annual weather-related variance, which is also a gain to risk averse, poor farmers.

The yield increase reported in [1] for 1999/2000, which was 40%, may not be unreasonable. Studies for developed countries show lower yield gains, but [10] and [11] compare commercial farms and smallholders in Argentina and find that the yield gain to large farms is 19%, while the smallholders gain 41%. This is remarkably similar to the South African results and the authors attribute the difference to the financial and human capital constraints that cause smallholders to invest less in chemical pest control, so their crop damage is higher. These reasons also apply to South African small-farmers. By the time a small-scale farmer has noticed bollworms, bought pesticides with a limited amount of credit and started to spray, severe damage has already been done. Many farmers indicated that they were not even able to apply pesticides on their whole field due to lack of time, knapsacks, labour and the cost of pesticide. With a low education level causing problems with the mixing of pesticides and the calibration of knapsack spraying nozzles, the efficacy and efficiency of pesticide applications is questionable for a large number of small-scale farmers.

3. Econometric Estimation of the Impact of the Bt Technology

3.1. Production Frontiers

Both yields and gross margins are incomplete indictors and say very little about the reasons for any observed differences between farms. Yield is a partial measure of productivity and is of limited use when the levels of non-land inputs used, such as labour and fertilizer, differ between farms. Gross margins take account of intermediate inputs, but ignore the efficiency with which the major inputs, labour and land, are used. All inputs are properly accounted for in production function estimation.

Whereas simple regressions take the average line of best fit through the observations (hence they are sometimes called mean response functions) and thus tacitly assume that all the farms are efficient, this can be misleading if there are significant differences in efficiency levels. Tests can show if the appropriate approach is a production frontier, which will give results that are more accurate and also generate efficiency levels for all the farms.

[1] explains cotton output with inputs of land, labour, chemicals and seed, differentiating between conventional and Bt varieties. The results are unambiguous, even in the first year, when the adopters had a far higher mean efficiency of 88%, as compared with the mean of 66% for those who did not use Bt cotton. This suggests that when all the inputs are included in the efficiency calculations, the adopters are 30% more efficient. The key point is that this analysis takes full account of the efficiency with which labour and land are used and these two inputs account for 70% (or more) of output in African agriculture. For 1999/2000, 73% of the variance in output was explained and the mean efficiency for the non-adopters was 48% and for the adopters, 0.74%. The efficiency advantage of the adopters has now risen to 54%, compared with 33% in the first season. Finally, the only variable that was significant in explaining the efficiency levels, in both years, was adoption of the Bt variety.

Pesticide productivity: why yields increase so much in smallholder agriculture

The estimation techniques above treat pesticide in exactly the same manner as the other inputs, but it actually adds nothing to output if there are no pests and when there are, it controls damage, keeping yields closer to what they would have been. Thus, in parallel with [12] for China and [10] and [11] for Argentina, [13] takes a 'damage control' approach to estimating the role of pesticides and Bt technology, which explains why [10] found relatively large yield gains in the case of smallholders.

As pesticide input increases, the abatement function approaches 1, so there is no destruction due to pest damage and maximum potential output is realized, but as pesticide application declines, it falls towards 0.The results for the conventional part of the model add nothing to those above, but the damage control parameters are highly significant, with signs that conform to expectations. Particularly, increasing pesticide does reduce damage and the Bt dummy variable is positive, which confirms that adoption of Bt varieties is effective in controlling pest damage, with less pesticide.

These results are illustrated in Figure 1, which shows the effect of pesticide per hectare use. The significant gap between the non-Bt and Bt curves illustrates the pest control efficacy of Bt adoption. With no pesticide applied, non-Bt producers would realize only about 16% of potential output. By shifting to Bt use, about 40% of potential output can be recovered even without application of insecticide. At each point, the slope of the Bt curve is lower than the slope of the non-Bt curve, suggesting that Bt adoption reduces the marginal productivity of pesticide by providing a natural substitute. At the current average application rate of 2.2 litres per hectare, a non-adopter attains only about 36% of potential output. A Bt user, at the current average application rate of 1.1 litres per hectare (half of the non-adopter average) realizes 55% of potential output. Although use efficiency cannot be determined without reference to input costs, realization proportions of 36% and 55% suggest under-use. Almost 9 litres would be required to get close to 100% output. Another key point to note from the diagram is that the non-Bt damage control curve is convex for a significant portion, indicating the increasing marginal efficacy of insecticide input at lower ranges. As will be seen below, this has an important implication for current use efficiencies.

Figure 1 here

The efficiency of insecticide use can be judged by comparing the Value Marginal Product (VMP) of insecticide with the insecticide price. The computations were done by holding all other inputs constant at the sample average values, while varying the quantity of insecticide. An additional litre of pesticide costs approximately 9.3 Rand ($0.93) per hectare, as Figure 2 shows.

Figure 2 here

Figure 2 is striking in that the VMP curve has an inverted U shape instead of the typical monotonically declining shape traditionally encountered. However, this is not too surprising given the convex non-Bt damage control curve encountered in Figure 1. Indeed, as [14] showed, this can be a fairly typical shape under the damage control specification and by ruling it out, conventional specifications like the Cobb-Douglas can miscalculate the productivity of pesticide input. The Figure shows that the current average level of 2.1 litres per hectare, is clearly sub-optimal, since it lies on the rising portion of the VMP curve. The correct level is 4.7 litres/ha, where the declining VMP intersects the input price. The calculations reveal that variable profits at this level exceed those at zero insecticide use by about 13 Rand ($1.3) per hectare. Thus, 4.7 litres per hectare is the optimal rate for the average producer and current level at 2.1 litres per hectare means that application is at less than 50% of the optimum.

Thus, whereas [12] reported overuse of 40 kg/ha in China, African smallholders use far too little pesticide and consequently suffer serious crop losses. This is why Bt gives impressive gains in yields in Makhatini Flats. There are several factors that could cause this outcome in Makhatini. First, there are financial reasons for under-use. Pesticide purchases often require larger cash outlays than are available to smallholders at Makhatini, particularly mid-season when reserves are low and other crops and activities compete for available cash. Many complain that they are unable to get sufficient credit. Others who can afford the chemicals, do not own a knapsack sprayer and would hire someone do perform the task. But, labour availability for spraying poses a similar dilemma. Over the Christmas period, an important time in the South African cotton cycle, hired labour is often unavailable [15]. Second, cross-sectional analysis is inevitably handicapped with regard to analysing pest problems. Pest infestations vary considerably between years and if farmers apply insecticide proactively on the basis of long-run experience, applications will be inadequate in a bad year. This season was unusually wet, which washes the pesticide reside off the plants, so that further application is required.

A similar analysis of the Bt users showed that the VMP curve was monotonically declining with increased pesticide applications. At current average applications rates of about 1 litre per hectare, Bt users are also under-applying insecticide relative to the optima of almost 2 litres per hectare. Thus, having halved pesticide inputs, Bt adopters are using about half the optimal amount of pesticide, like the non-adopters. Although the Bt gene provides resistance to the bollworm, so that bollworm-specific pesticides sprays are no longer needed, [16] note that the leaf hoppers and aphids are causing increasing damage. Clearly, the current applications of pesticides to deal with these other pests are inadequate. Indeed, if adequate pesticide were used for these pests, they would replace the bollworm chemicals, leaving the overall application rate close to its initial level.

For both the adopters and non-adopters, these private optimal application rates take no account of the environmental and health costs of pesticide use, which would reduce the socially optimal application rates. Thus, the under-use reported here would be reduced if these negative externalities could be measured and allowed for.

Institutional failure

This review shows that Bt cotton had been adopted by over 90% of the cotton farmers in Makhatini Flats and seemed to over substantial advantages over non-Bt cotton varieties. Indeed, despite the variability of benefits the evidence shows that Bt cotton is technologically superior as the expected yield is higher and the variance is lower. The institutional arrangements were also successful. The Land Bank supplied credit and the risk of default was shared between the Land Bank and Vunisa. Vunisa administrated production loans from the1998/99 season and there was a loan recovery rate of close to 90%.

Then, in 2001/2 a new company, Makhatini Cotton (Pty) Ltd (MCG) erected a new gin on the Flats, right next to the Vunisa depot. Some farmers avoided repaying their loans by selling to the new gin and having lost substantial sums, in 2002/3 Vunisa was no longer offering inputs on credit. There is a clear lesson here that is widely understood already in African conditions. The only asset that can be used as collateral for a loan is the crop itself. Loans are not made for maize as the farmers can eat it, but with cotton, if there is only one mill, the company owning the mill can make loans. If there is more than one mill the farmers will default and inability of financial corporations to enforce repayment of loans, combined with the fact that most farmers on the Flats cannot finance their own cotton production inputs, means little production.

Thus whereas with complete markets there are policies to preserve competition and prevent rent seekers from obtaining monopoly profits, in this situation monopsony needed to be maintained. Until the institutional arrangements are changed in such a way that lenders can recover their loans, an alternative approach is required. Makhatini Cotton do the planting and the farmers receive a share of the revenue for weeding, harvesting and otherwise caring for the crop This approach does not solve the principal and agent problem either, as some farmers steal the cotton (produced on their own land) to deliver it to Vunisa or even to MCG. It may transpire that MCG is showing great initiative and determination in trying to establish irrigated cotton and maize or wheat production units with the aim of establishing small-scale farmers on these areas over the longer term, but so far it has simply created a monopoly that leaves the farmers no choice at all.

Conclusions: Implications for African Agriculture

The history of Bt cotton in Makhatini Flats shows the technological potential of GM crops in an African smallholder environment. But it also shows that good governance and institutional structure is required or the potential gains will not be realised. It is not reasonable to expect the farmers to change their behaviour quickly: they have seen a procession of failed schemes and broken promises. The South African Development Trust Corporation (STK), the Department for Development and Aid (DDA), the KwaZulu Finance and Investment Corporation (KFC) and the Development Bank of South Africa (DBSA) have all had roles in credit provision on the Flats over the years. Scientific advances really are easier than establishing the social and economic conditions necessary for progress to occur.

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Figure 1: Damage control

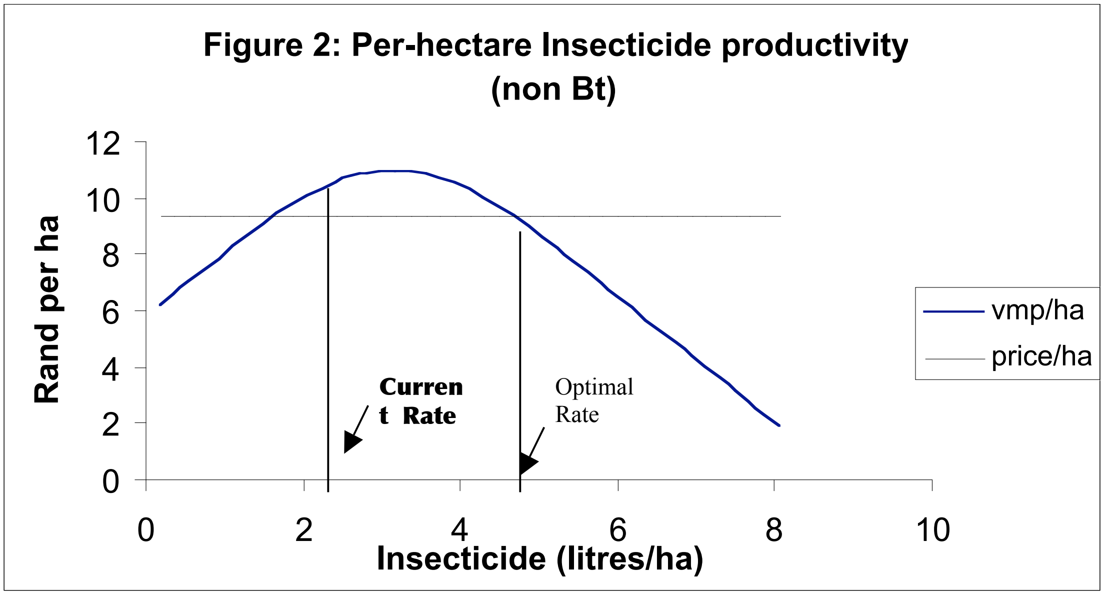

Figure 2: Per-hectare Insecticide productivity (non Bt)